Online Appendix to
"Will Perturbing Soil Moisture Improve Warm-Season Ensemble Forecasts? A Proof of Concept"
by Sutton et al.

This appendix provides a detailed description of the forecast differences for four more cases, in addition to the two described in Sutton et al. (2005).

a. 22 August 2001

Figure A-1a shows the 500 hPa geopotential and sea-level pressure pattern on this day. At 500 hPa there was a narrow ridge with an axis approximately along the Mississippi Valley, with southwesterly flow to the west of this ridge. The most notable aspect of the surface-pressure pattern was a strong southerly flow extending from Texas to the Great Lakes. Precipitation in the subsequent 24 h was observed (Fig. A-1 b) in a band from northeast Kansas to northeast Ohio, with maxima in northeast Kansas, western Illinois, and northeast Indiana. There were damaging-wind reports in Illinois and Indiana. The top-level NOAH soil moisture (Fig. A-1 c) was high over the region where precipitation was observed, a consequence of precipitation in the previous days. The top-level MOSAIC soil moisture (Fig. A-1 d) was similar to that from NOAH in regions from the Missouri valley to Illinois, but it was generally drier elsewhere.

The NOAH5 forecast precipitation (Fig. A-1 e) produced 24-h amounts exceeding 80 mm over the border of Missouri, Illinois, and Iowa. This maxima roughly corresponded in location to one of the observed maxima, but the forecast amounts were too high. The NOAH5 did not produce much precipitation near the observed maximum in northeast Kansas. Figure A-1 f showed that the MOSAIC5 precipitation maximum was comparable in amount but occurred to the west of the NOAH precipitation maximum. The 2-m temperatures in NOAH5 (Fig. A-1 g) were largest in Central Kansas and cooler towards the Great Lakes. MOSAIC-5 temperatures were generally about the same or cooler (Fig. A-1 h).

Figure A-2 a shows that the accumulated-precipitation maximum for the NOAH20KF simulation was greater than 60 mm in a band through central Illinois. The MOSIAC20KF forecast differences (Fig. A-2 b) were small in scale but forecast generally more intense precipitation over Missouri west of the NOAH maximum, with common differences in precipitation between the two forecasts of 5-10 mm. The 2-m forecast temperatures from NOAH20KF (Fig. A-2 c) were commonly slightly cooler than the NOAH5 forecast in the southern half of the domain. The MOSAIC20KF was more commonly cooler than NOAH20KF, especially along the Missouri River.

Figure A-3 a shows the NOAH20BMJ forecast precipitation, which was displaced south of the precipitation in the NOAH20KF simulation (Fig. A-3 b). NOAH20BMJ forecast a wide area of 2-5 C warmer temperatures at 0000 UTC 23 August 2001 (Fig. A-3 c). This was due primarily to early-afternoon convection in the NOAH20KF simulation through central Missouri that had not yet occurred in the NOAH20BMJ simulation (though the NOAH20BMJ eventually did produce long-lasting convection there overnight).

b. 11 June 2002

At the surface (Fig. A-4 a) there was a low-pressure system over Northern Michigan and a trough of low pressure extending down and beyond another low in Kansas. Relatively strong southerly winds extended from the Gulf Coast of Texas to Iowa and the Great Lakes. At 500 hPa there was a broad trough over the northern Rockies and a ridge along the Gulf Coast. Precipitation over the subsequent 24 h extended from Kansas to Indiana and the western Great Lakes (Fig. A-4 b), with maximum precipitation of > 60 mm observed in western Illinois. Damaging winds and a few tornadoes were reported from eastern Kansas to Illinois. The NOAH soil moisture (Fig. A-4 c) was relatively wet compared to the other case days, with moderate soil moistures west of the Missouri River and a localized maximum of soil moisture in eastern Nebraska, due to recent rainfall. MOSAIC top-level moisture was typically drier than NOAH (Fig. A-4 d) to the west of the Mississippi River and slightly wetter to the east, and wetter in southern Missouri as well. The unusual rectangular patches of differences can be traced to problems with the NOAH soil moisture analysis on this day.

NOAH5 forecast very heavy precipitation amounts along a north-south line through central Missouri (Fig. A-4 e) with a widespread surrounding area of 10 mm or greater. The MOSAIC5 differed in the location of individual cells but had rainfall of the similar magnitude and general area as NOAH5 (Fig. A-4 f). Note the extensive area with differences of 10 mm or larger. The notable feature in the NOAH5 12-h forecast of 2-m temperature was a chain of outflow boundaries through northeastern Missouri, central Illinois, and western Indiana (Fig. A-4 g). The positions of these outflow boundaries were subtly different in MOSAIC5 (Fig. A-4 h), and many grid points along the boundary had temperature differences of 1 K or greater.

Figure A-5a shows that the maximum (> 80 mm) in the NOAH20KF forecast occurred over northern Indiana, further to the northeast than in the NOAH5 simulation. Also, the axis of heaviest precipitation was aligned east-west as opposed to the north-south organization in NOAH5. The precipitation in MOSAIC20KF had about the same magnitude and spatial coverage as NOAH20KF but differed in the locations of the most convectively active grid points (Fig. A-5 b). The 2-m temperature forecast in Fig. A-5c does not show the outflow boundaries evident in the explicitly resolved simulations. The 2-m temperature differences between the soil moisture initializations at 20-km grid spacing were generally small (Fig. A-5 d).

The choice of the convective parameterization had a strong impact on precipitation location and amount. Figures A-6a shows the precipitation from NOAH20BMJ, which had a smaller, 20-40 mm maximum in northern Illinois and Indiana and other maxima in southeast Nebraska and eastern Missouri. The NOAH20BMJ precipitation was much lighter than the NOAH20KF precipitationin northern Missouri, but NOAH20BMJ precipitation was more widespread (Fig. A-6 b). Overall, the precipitation differences were both large in magnitude and in scale. The 2-m temperature differences associated with the different parameterizations (Fig.A-6 c) show that the NOAH20BMJ was cooler than the NOAH20KF forecast by 1-2 C in a band northeast from central Missouri, and warmer over parts of Kansas.

Overall, the choice of soil moisture initializations subtly changed the location of precipitation maxima. Precipitation differences at individual grid points due to a change in soil moisture were relatively large at 5 km but smaller at 20 km with parameterized convection. The choice of cumulus parameterizations dramatically affected precipitation amount and location.

c. *27 July 2002*

This case day was characterized by a weak surface high over northwest Colorado and a trough extending from the Dakotas to western Texas (Fig. A-7 a). There was relatively strong westerly flow at 500 hPa for this time of year through Nebraska and Iowa. Precipitation occurred in isolated patches (Fig. A-7 b); the patch of greatest interest here was the 20-40 mm amounts in central Kansas. There were scattered reports of hail and damaging winds along with this convective rainfall. The NOAH soil moisture analysis showed a general gradient of soil moisture, with moister values to the east and drier to the west (Fig. A-7 c). The top-level MOSAIC soil moisture was almost uniformly drier across the domain (Fig. A-7 d).

We chose to concentrate on the precipitation maximum in Kansas. In this case, the 5-km forecasts were clearly poor precipitation forecasts. Figure A-7e shows the NOAH5 precipitation, which did not forecast any significant convective rainfall in central Kansas. Apparently, on this day with a "loaded gun" thermodynamic profile (Fig. A-8), the model did not forecast the penetrative convection that eventually occurred. The MOSAIC5 was only slightly better; it forecast a few cells in northeast Kansas, but was also much drier than observed (Fig. A-7 f). The NOAH5 2-m temperature forecast (Fig. A-7 g) produced temperatures of greater than 35 C in central Kansas at 0000 UTC 28

July. The MOSAIC5 forecast (Fig. A-7 h) was cooler in parts of Nebraska, but warmer by 1-2 C from northeastern Oklahoma through west-central Missouri.

For this case day, the 20-km parameterized forecasts were more realistic than the 5-km explicit convective forecasts, with the NOAH20KF producing a band of thunderstorms extending northeast from central Kansas (Fig. A-9 a). The MOSAIC20KF simulations were slightly moister with precipitation shifted a bit to the east (Fig. A-9 b), and generally cooler in the northern half of the domain (Fig. A-9 d).

The NOAH20BMJ simulation also forecast precipitation in a band extending northeast from central Kansas (Fig. A-10 a) but the precipitation was less intense and shifted slightly east (Fig. A-10 b). The surface temperatures (Fig. A-10 c) were warmer under the area where NOAH20KF produced more precipitation and cooler to the east where the NOAH20BMJ produced more precipitation.

d. 11 August 2002

At initialization time, a surface trough was located in the lee of the Rockies, and areas from Oklahoma north through the Dakotas and Great Lakes were experiencing southerly surface wind flow. The region east of the northern Rockies was experiencing diffluent flow at 500 hPa during 11 August (Fig. A-11 a). The precipitation occurred in two general patches, one region with 20-40 mm through northern Oklahoma and southern Kansas, and a second, more widespread region covering parts of Nebraska, South Dakota, Iowa, Minnesota, and Wisconsin, with a maximum of > 40 mm in central Wisconsin (Fig. A-11b). We again focus on the precipitation maximum over Kansas and

Oklahoma. On this day there were several tornadoes in Kansas, North Dakota, and Minnesota, and hail and damaging wind reports throughout the region receiving precipitation. Soil moistures were moderate throughout most of the domain (Fig. A-11 c), with moister analyzed soil conditions in the Texas panhandle and southern Missouri. The MOSAIC top-layer analyzed soil moisture was typically drier than NOAH (Fig. A-11d).

Both 5-km simulations (Figs. A-11 e-f) dramatically under-forecast the precipitation in Oklahoma and Kansas, another poor precipitation forecast. MOSAIC5 temperatures were cooler at 0000 UTC over much of the northern part of the domain, primarily due to the greater sub-surface moisture (not shown).

As in the previous case, the 20-km forecasts produced precipitation that was more widespread than either 5-km simulation, with patchy convection in the NOAH20KF over Oklahoma, Kansas, Missouri, and Illinois (Fig. A-12 a) and a maxima in excess of 20 mm. Precipitation in MOSAIC20KF was forecast in a similar region, though the slightly different positions of individual cells led to differences of 5-10 mm. The NOAH20KF forecast (Fig. A-12 c) forecast temperatures of 33 C in Kansas west of the convectively active region and cooler in eastern Kansas as a consequence of the convection. The MOSAIC20KF predicted generally cooler temperatures in the north than in NOAH20KF. The pattern of temperature differences in the 5 and 20-km simulations were very similar outside of the region of convection.

The NOAH20KF produced a much more realistic precipitation forecast than the NOAH20BMJ (Fig. A-13 a), which forecast virtually no convection over Kansas or

Oklahoma. Without the convection forecast, the temperatures were commonly 2-5 C warmer.

Figure captions

Figure A-1: As in Fig. 2 from Sutton et al., but for 22 August 2001.

Figure A-2: As in Fig. 4 from Sutton et al., but for 22 August 2001.

Figure A-3: As in Fig. 5 from Sutton et al., but for 22 August 2001.

Figure A-4: As in Fig. 2 from Sutton et al., but for 11 June 2002.

Figure A-5: As in Fig. 4 from Sutton et al., but for 11 June 2002.

Figure A-6: As in Fig. 5 from Sutton et al., but for 11 June 2002.

Figure A-7: As in Fig. 2 from Sutton et al., but for 27 July 2002.

Figure A-8: Rawinsonde sounding from Topeka, Kansas at 0000 UTC 28 July 2002.

Figure A-9: As in Fig. 4 from Sutton et al., but for 27 July 2002.

Figure A-10: As in Fig. 5 from Sutton et al., but for 27 July 2002.

Figure A-11: As in Fig. 2 from Sutton et al., but for 11 August 2002.

Figure A-12: As in Fig. 4 from Sutton et al., but for 11 August 2002.

Figure A-13: As in Fig. 5 from Sutton et al., but for 11 August 2002.

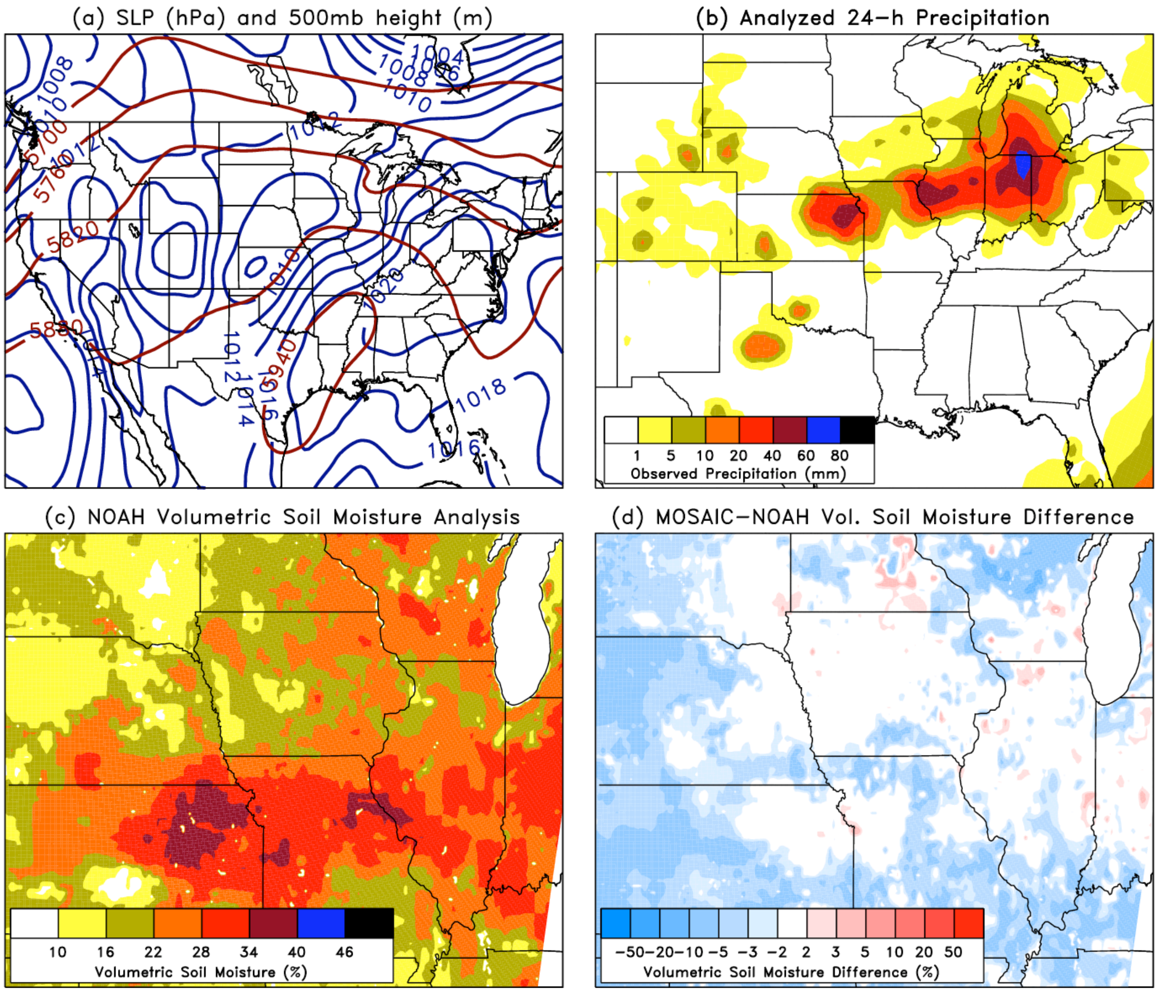
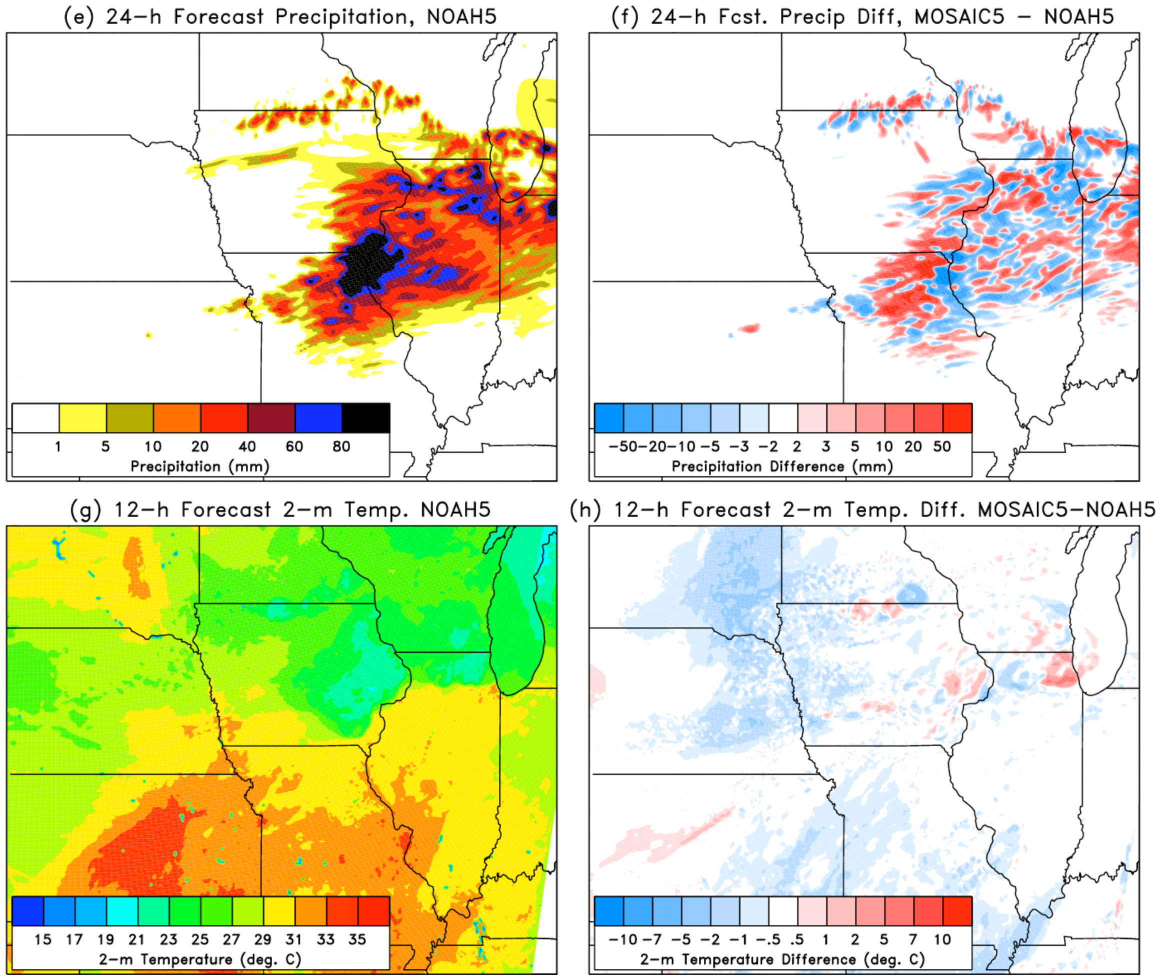


Figure A-1: see caption on next page.



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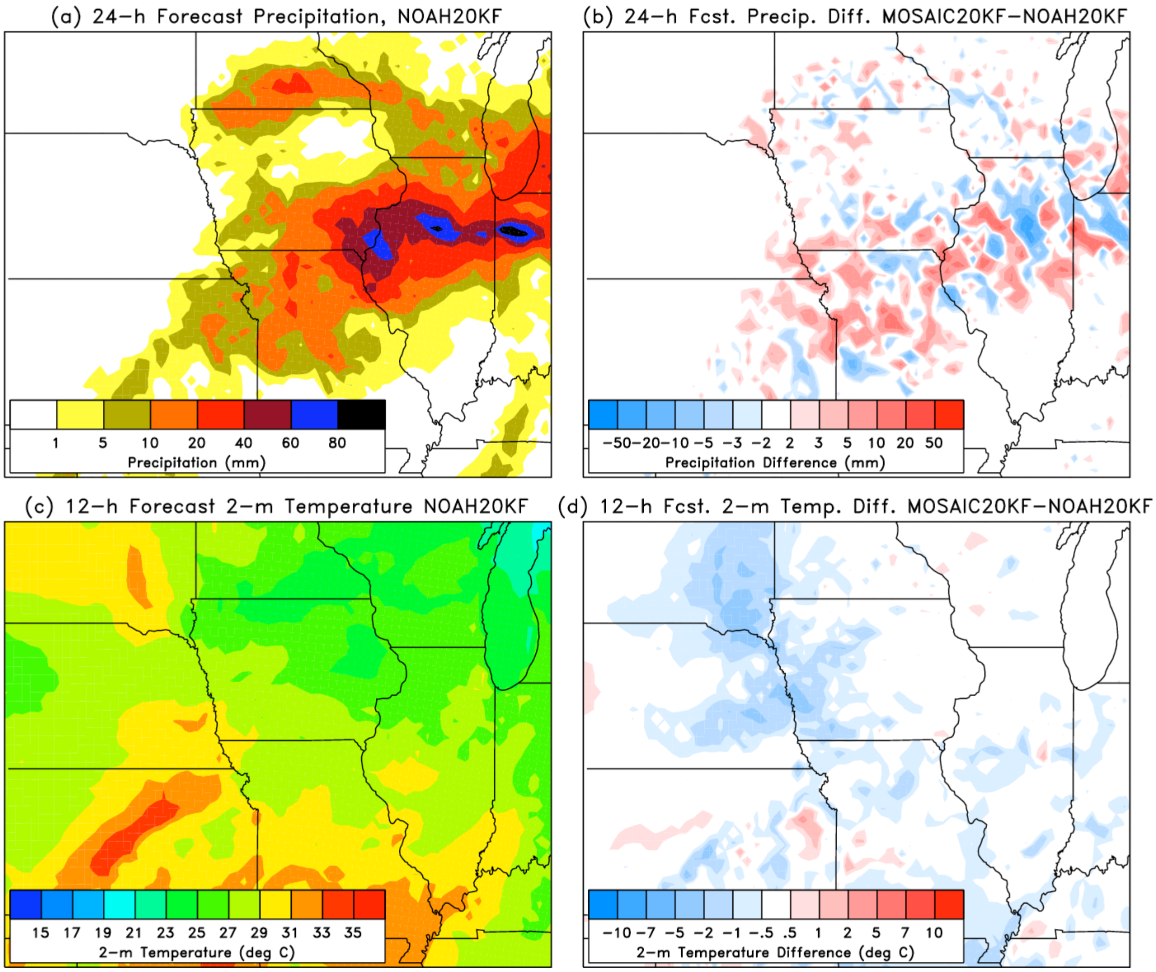


Figure A-2: As in Fig. 4 from Sutton et al., but for 22 August 2001.

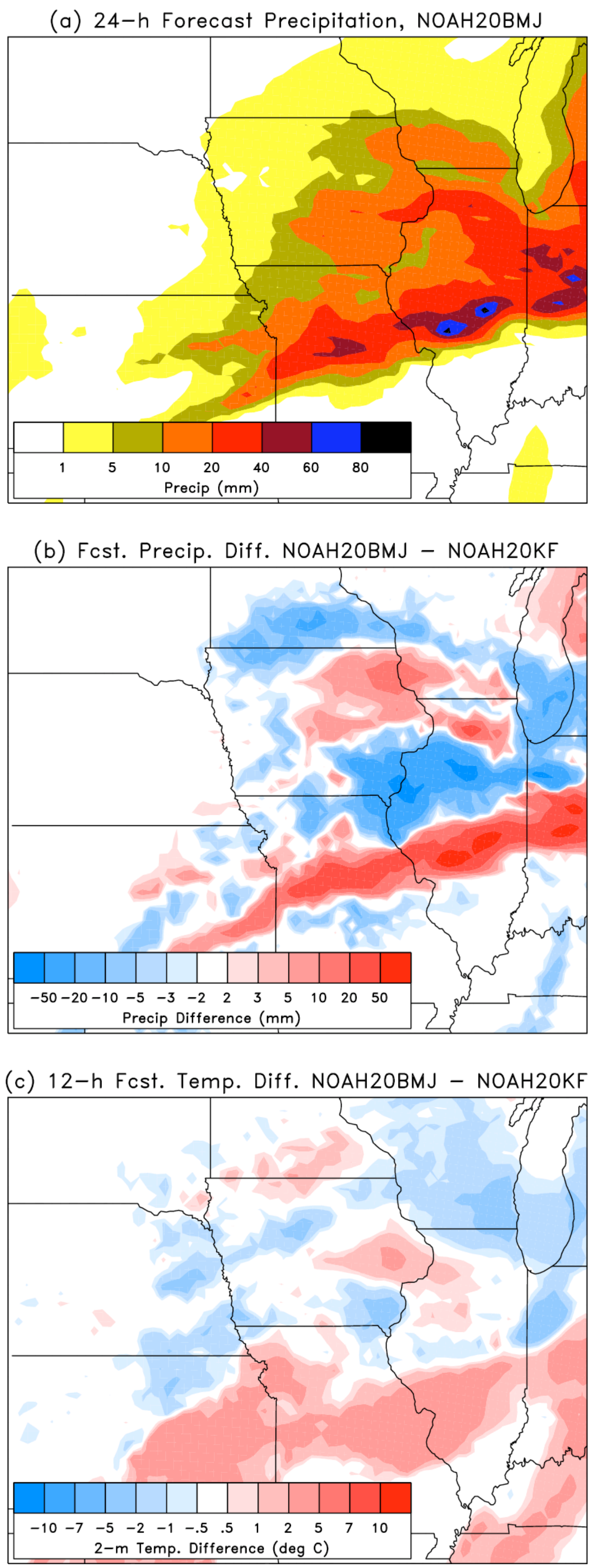
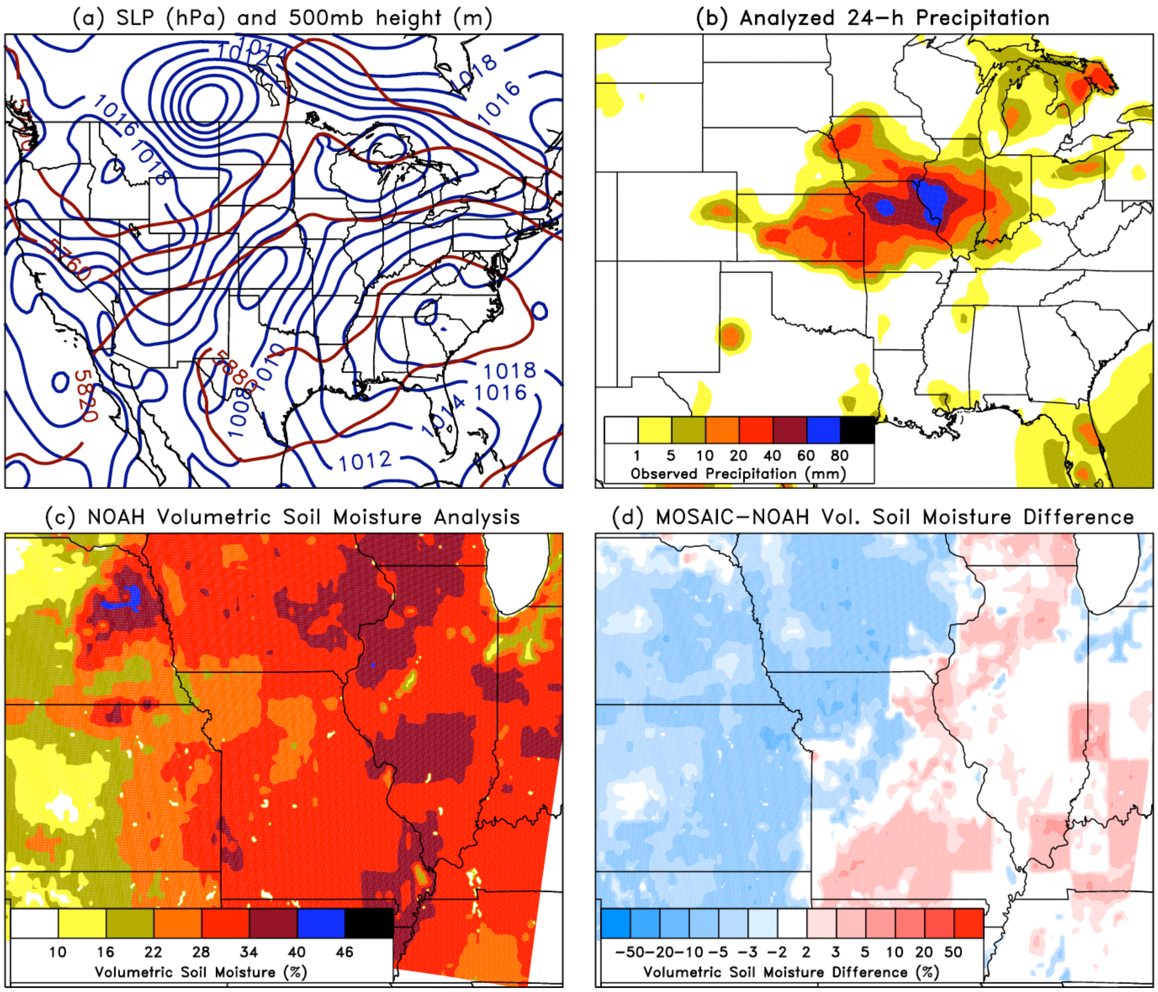


Figure A-3: As in Fig. 5 from Sutton et al., but for 22 August 2001.



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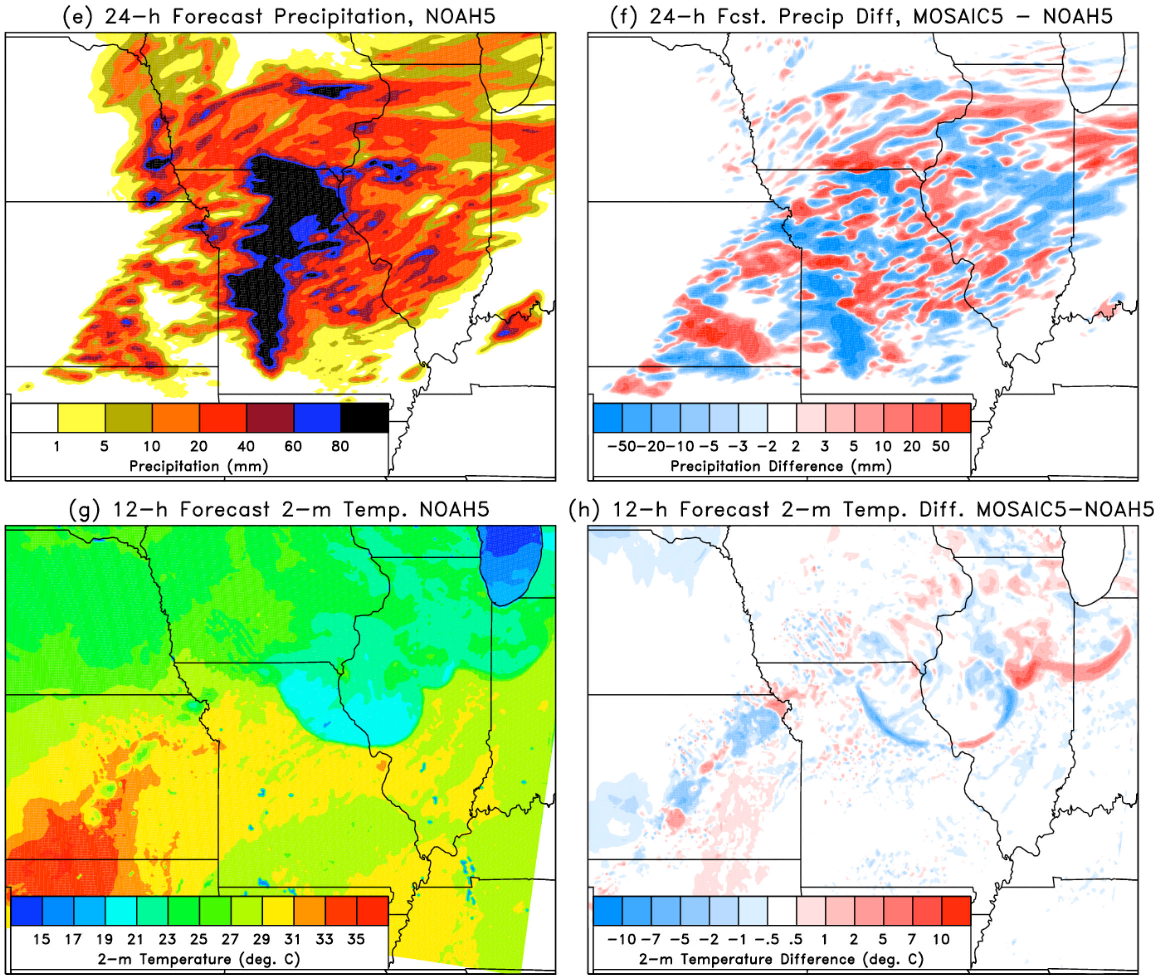


Figure A-4: As in Fig. 2 from Sutton et al., but for 11 June 2002.

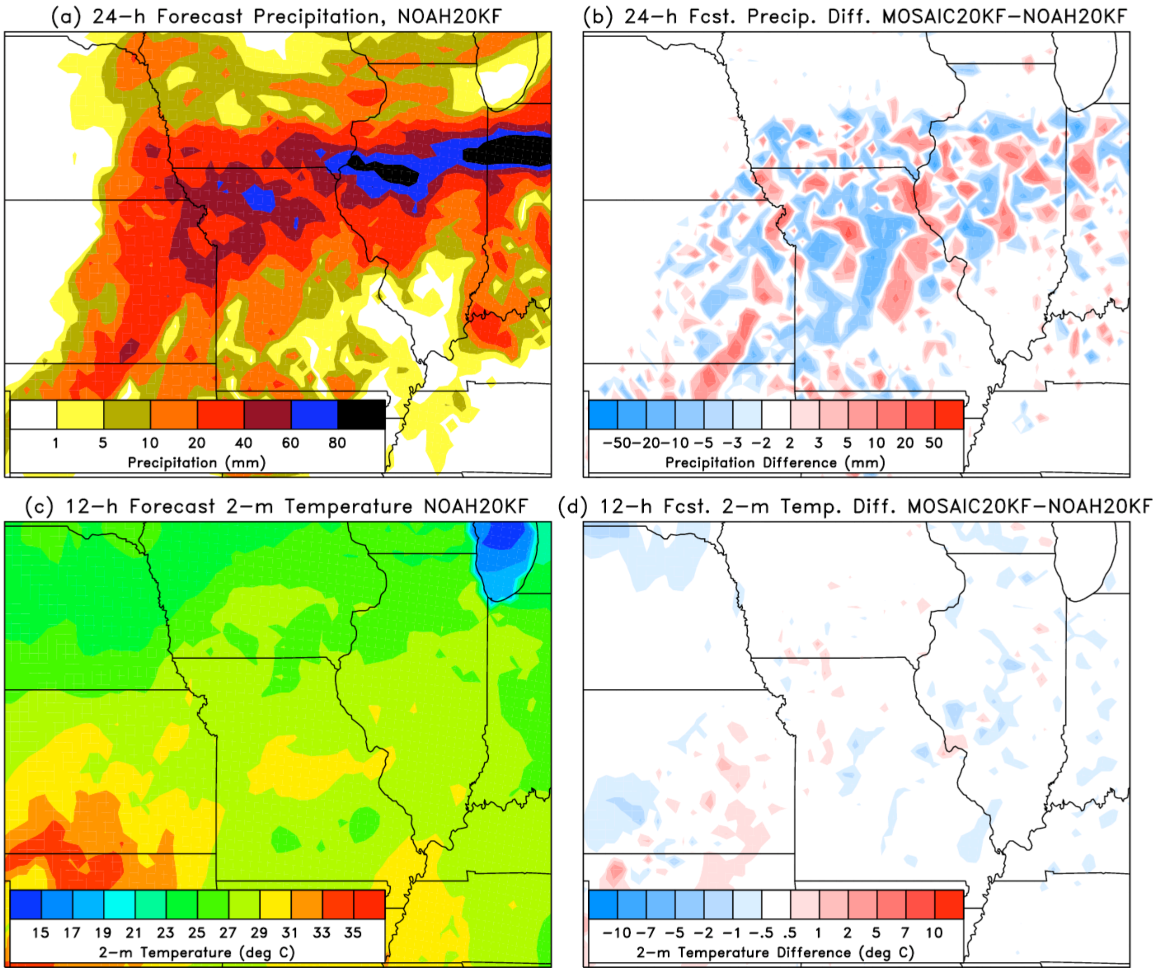


Figure A-5: As in Fig. 4 from Sutton et al., but for 11 June 2002.

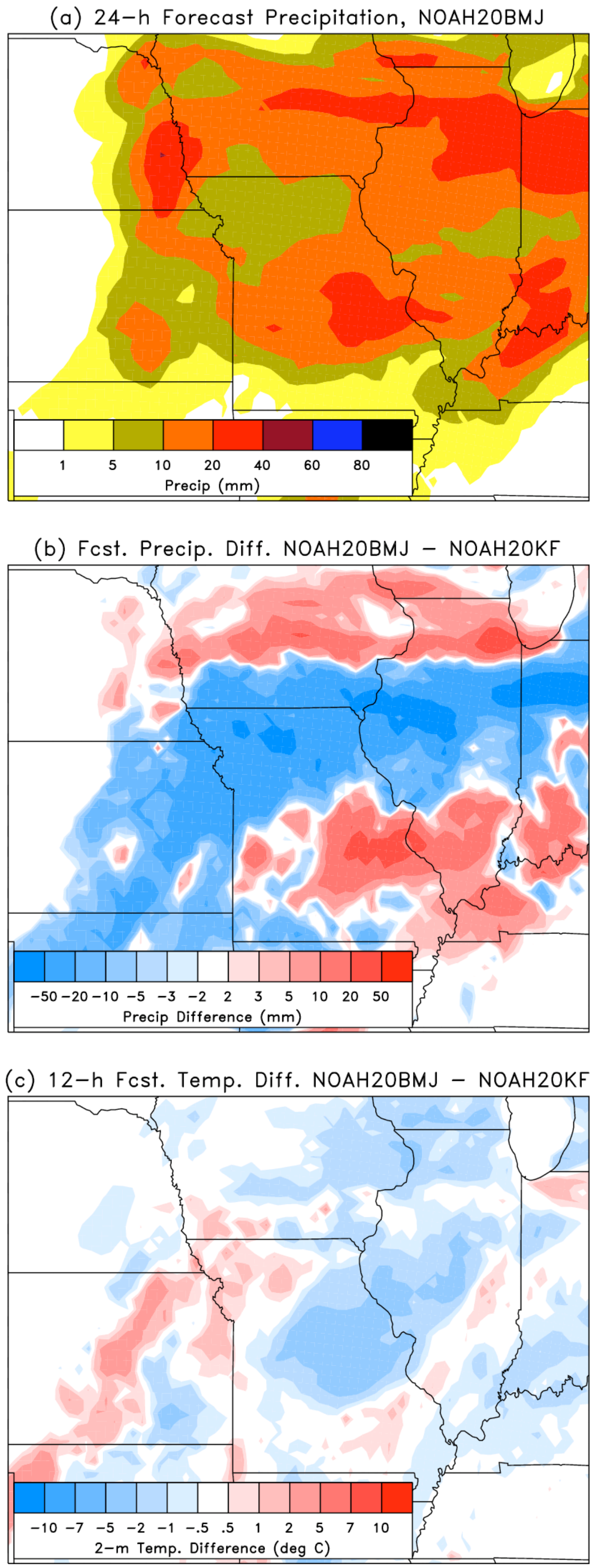


Figure A-6: As in Fig. 5 from Sutton et al., but for 11 June 2002.

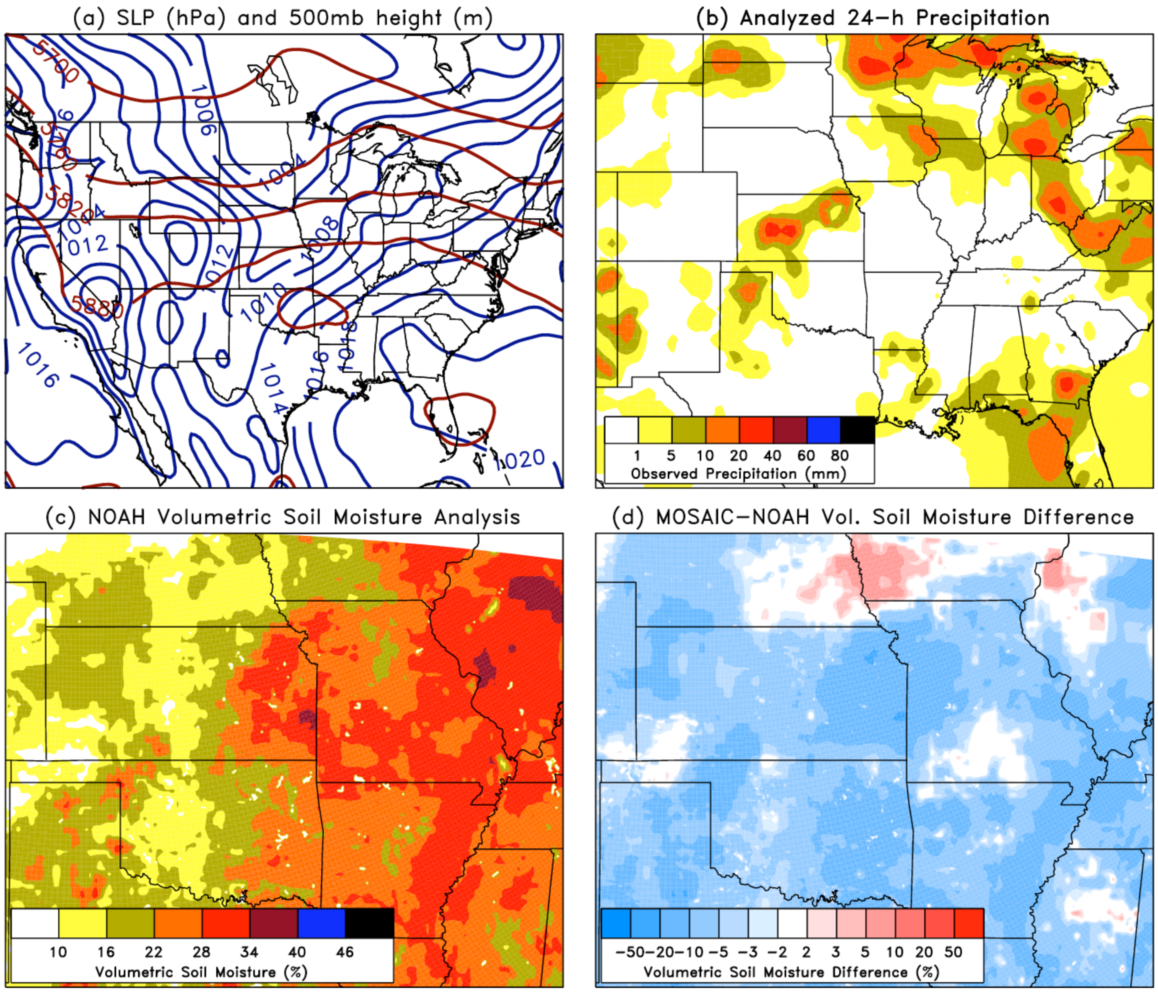


Figure A-7: See caption on next page.

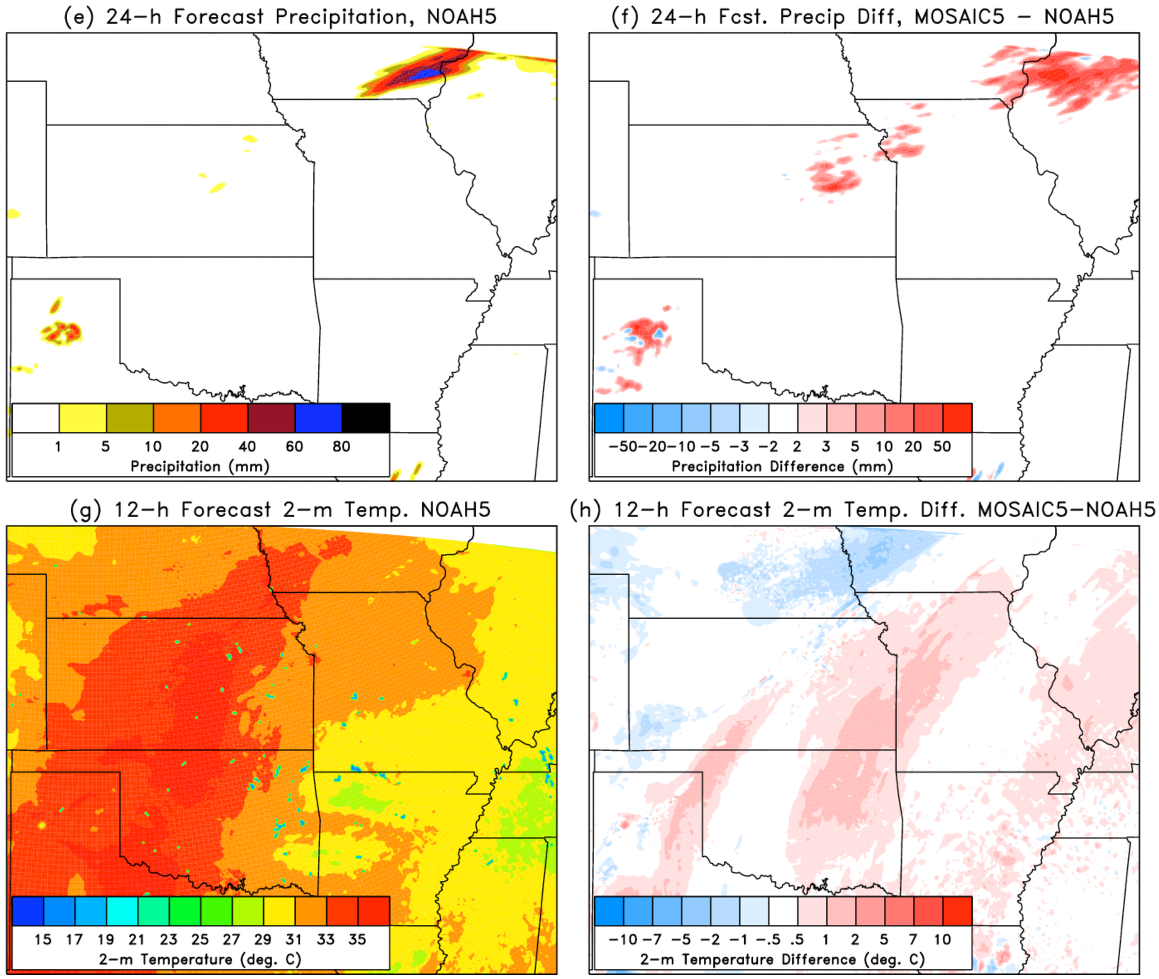


Figure A-7: As in Fig. 2 from Sutton et al., but for 27 July 2002.

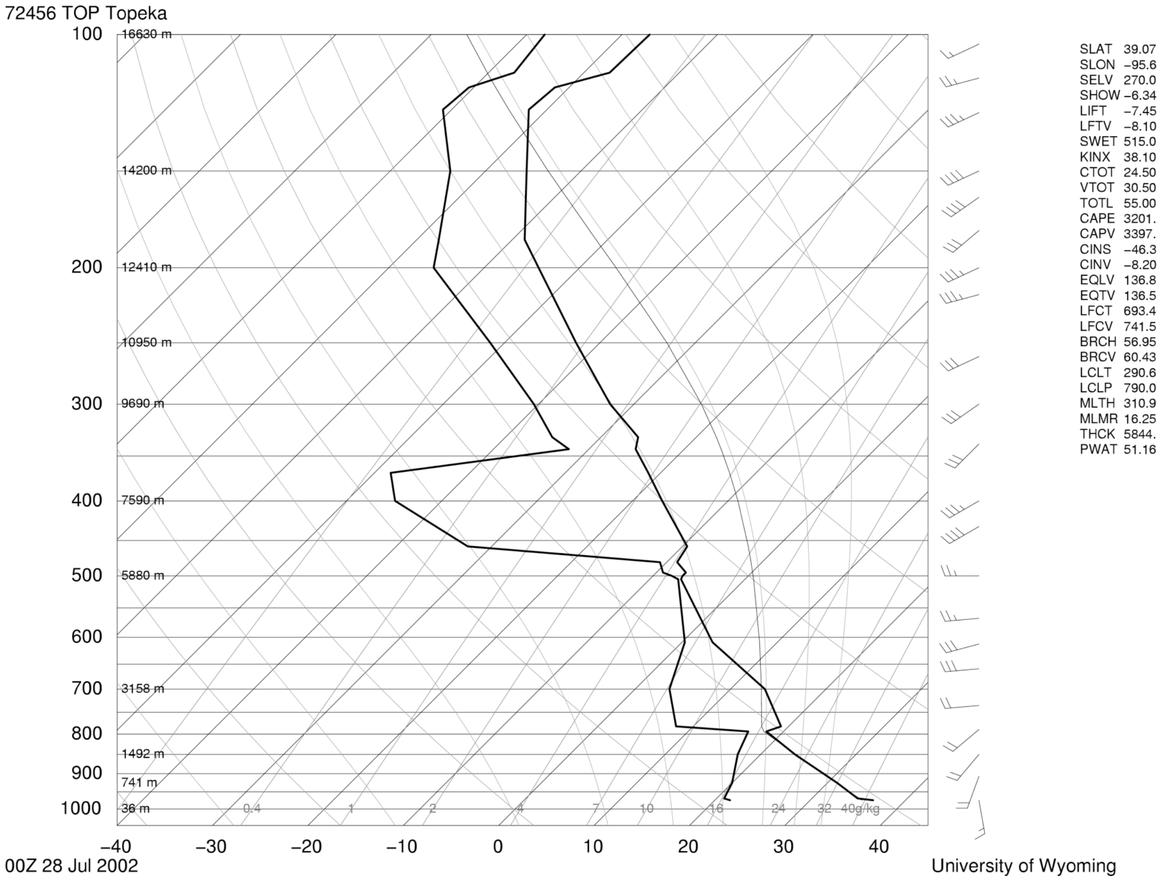


Figure A-8: Rawinsonde sounding from Topeka, Kansas at 0000 UTC 28 July 2002.

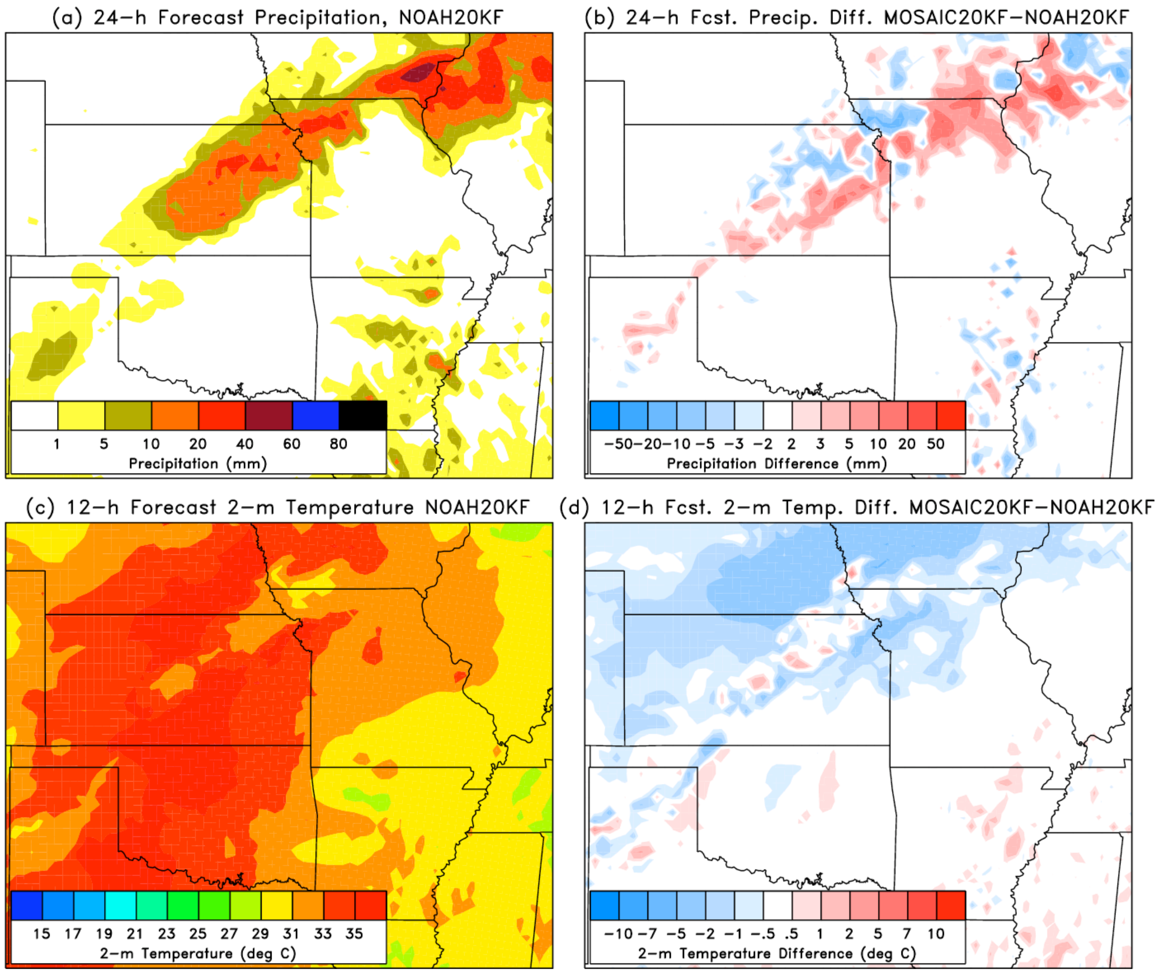


Figure A-9: As in Fig. 4 from Sutton et al., but for 27 July 2002.

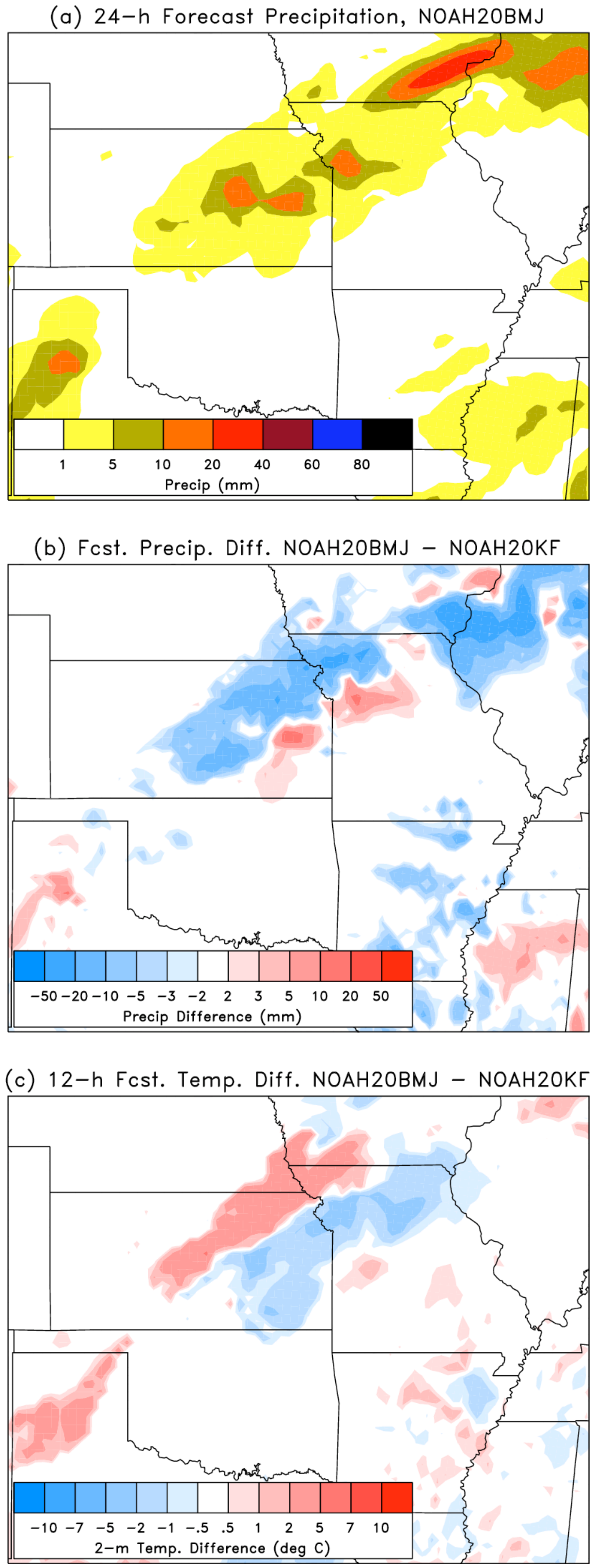
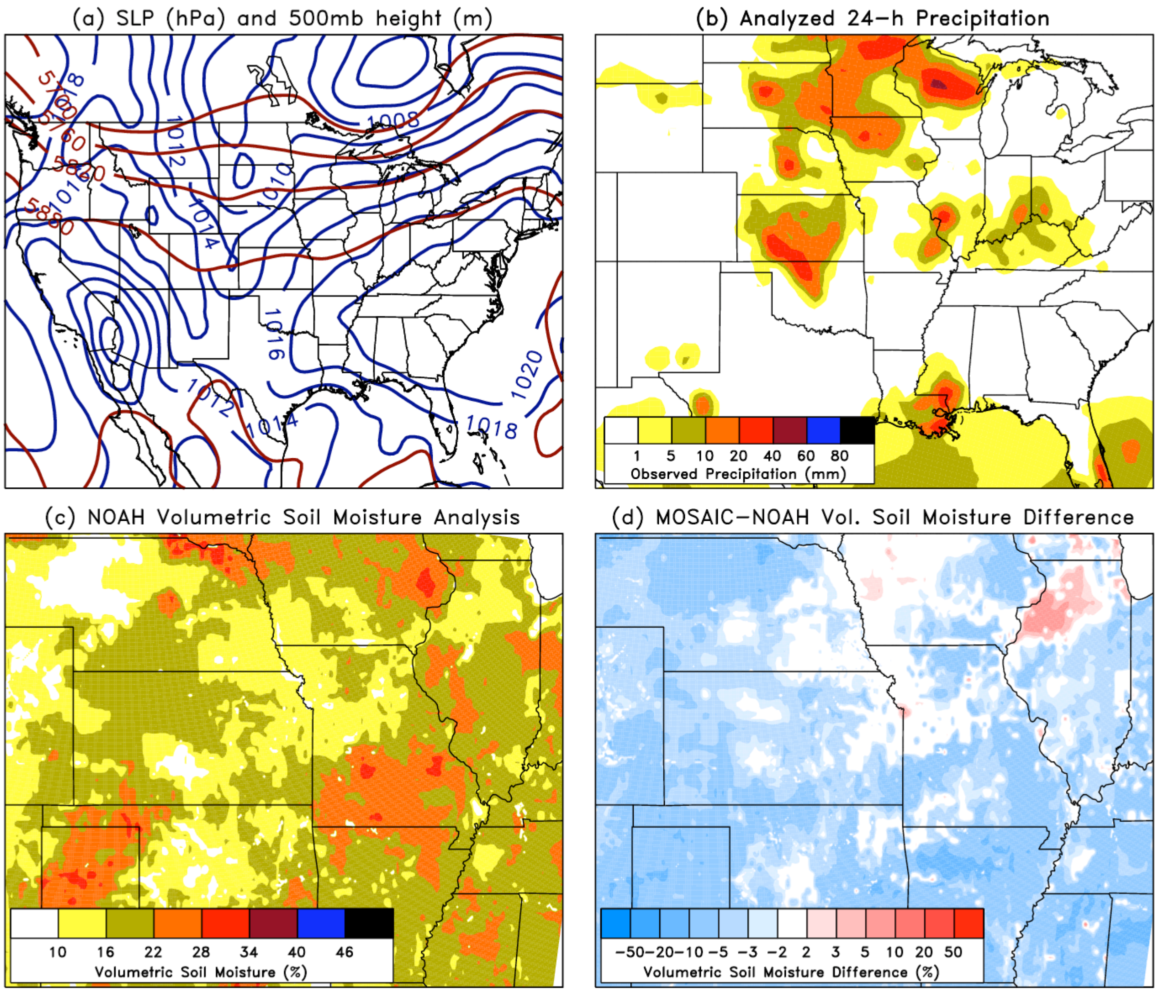


Figure A-10: As in Fig. 5 from Sutton et al., but for 27 July 2002.



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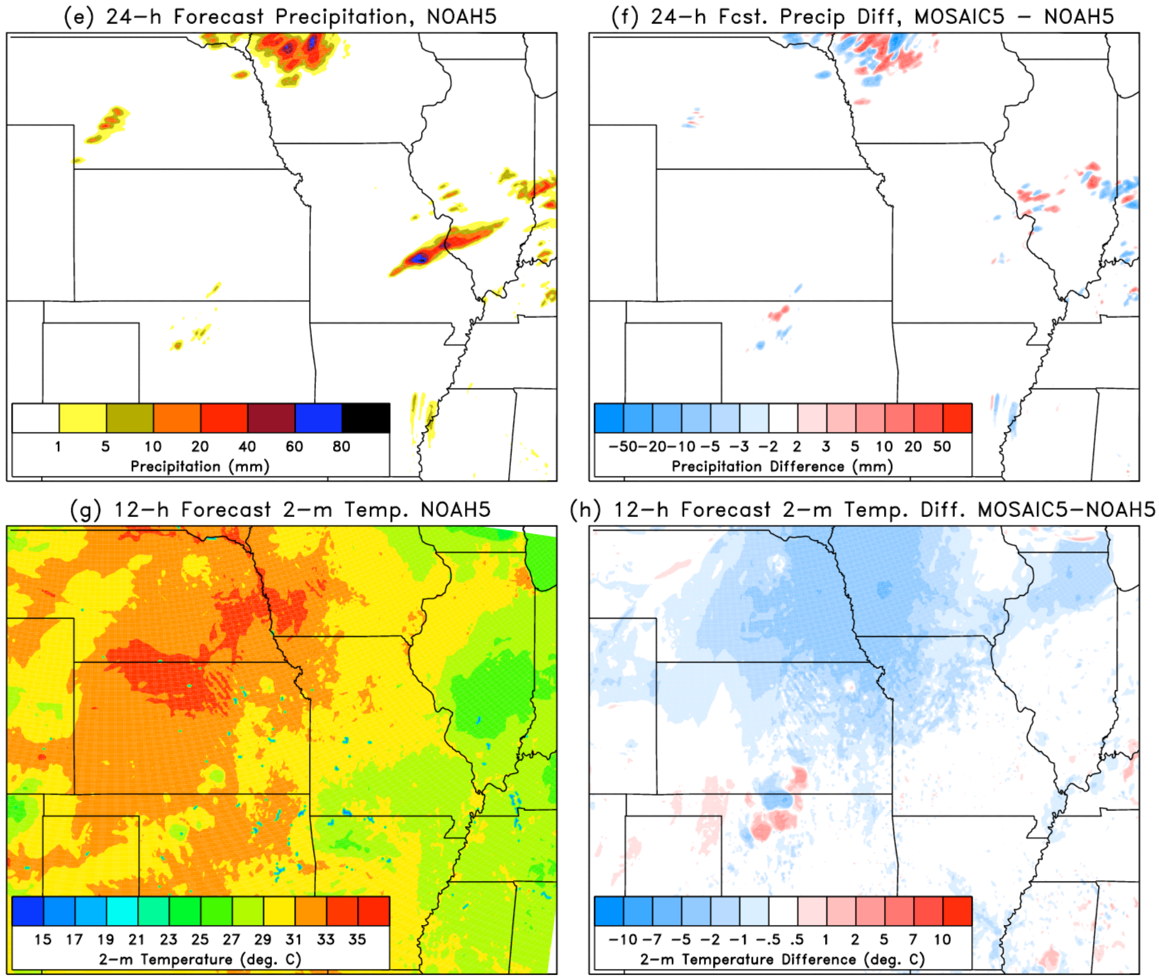
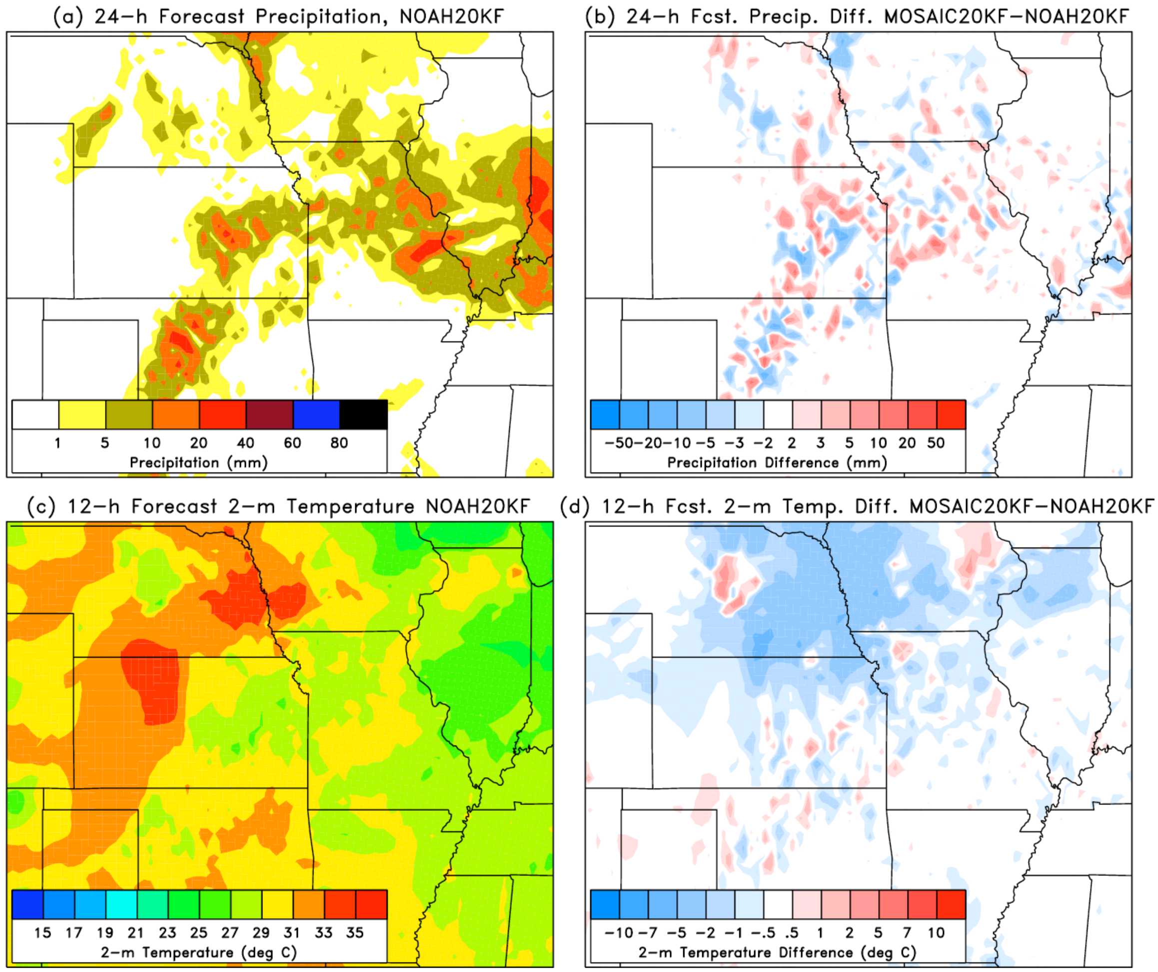


Figure A-11: As in Fig. 2 from Sutton et al., but for 11 August 2002.



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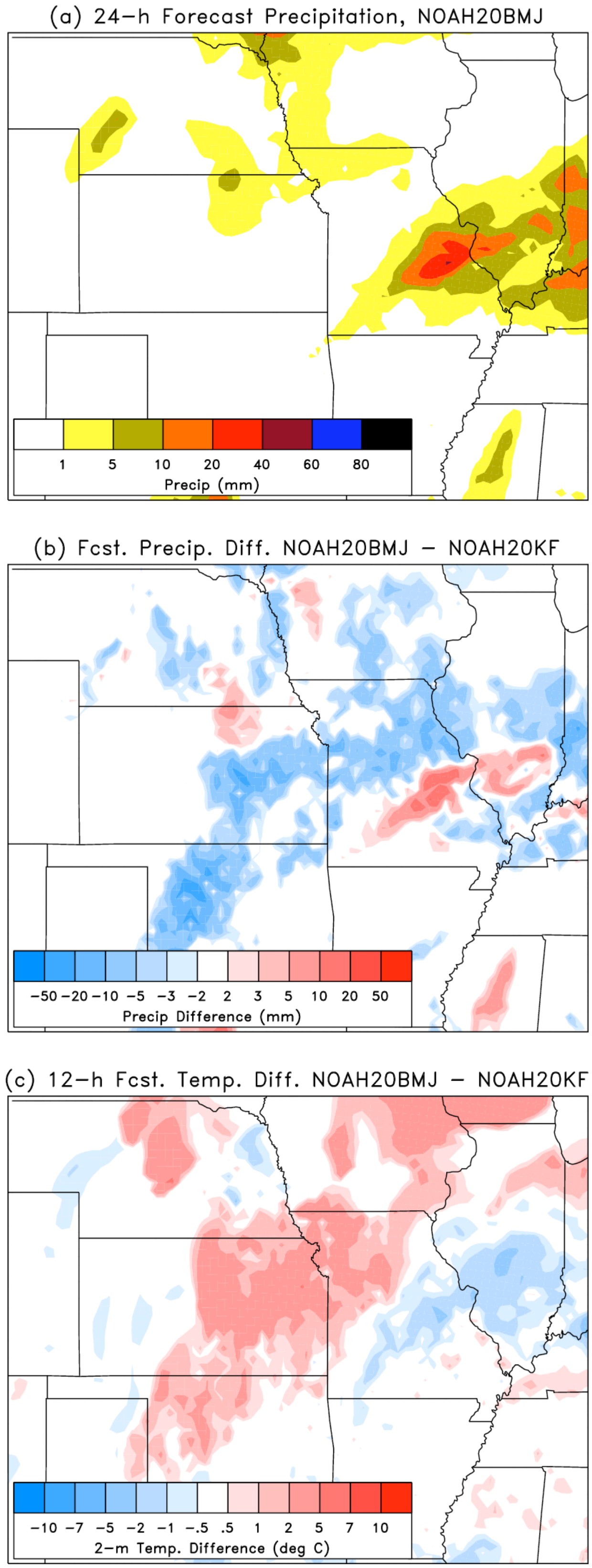

Figure A-13: As in Fig. 5 from Sutton et al., but for 11 August 2002.